Learning and technological capability building in emerging economies: the case of the biomass power equipment industry in Malaysia

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1. INTRODUCTION

There is often a tendency to think of sustainable development separately from processes of technological capability development in developing countries via the transfer/import of foreign technologies. For example, recent special issues of the development studies journal *World Development* dealt separately with the topics of "Sustainable Development, Energy and Climate Change" (Halsnæs et al., 2011) and "Foreign Technology and Indigenous Innovation in the Emerging Economies" (Fu et al., 2011). An emerging literature, however, is beginning to highlight how these issues are in fact inextricably linked and how an understanding of the latter might make a critical contribution to realising the former, i.e. sustainable development pathways that incorporate lower carbon energy technologies, contributing to climate change mitigation whilst simultaneously meeting critical development priorities (Mathews, 2007; Altenburg, 2008; Walz, 2010; Ockwell et al, 2010; Berkhout, 2012). But simply transferring lessons from research on conventional technology imports and indigenous innovation is not enough. Climate change and technologies for its mitigation or adaptation poses a range of unique challenges and considerations which are currently under researched and under theorised (Ockwell and Mallett, 2012). These include temporal concerns relating to the urgency of climate change mitigation (i.e. achieving extensive low carbon technology transfer as quickly as possible), the global good nature of the benefits of low carbon technologies which are not captured in the market (Mowery et al., 2010), ignored needs of the poorest people where market incentives are also lacking (Sagar, 2009), and the early stage of commercial development and adoption of many low carbon technologies, raising multiple risks to their commercial use and barriers to investment. However, despite the lack of an empirical or conceptual base upon which to build, in many development organisations, including donors, NGOs, and international development banks, the use of phrases such as “low carbon development”, “climate compatible development” and “green growth” have become increasingly widespread and are shaping funding agendas. There is therefore an urgent need for empirically grounded research which explores theories of foreign technology and indigenous innovation explicitly within the context of low carbon energy technologies, and the contexts of climate change and development policy more broadly. It is within this context that this paper seeks to contribute.

A number of studies have recently begun to analyse how low carbon energy technology industries in emerging economies have evolved and proliferated in parallel with rapidly expanding renewable energy markets and overseas investments. A key question addressed in these studies is the extent to which foreign investment has increased indigenous capabilities in developing countries to engage in advanced product development (Brewer 2008; Altenburg, 2008; Lema and Lema, 2012). Existing work pays particular attention to the role of national political and institutional conditions for industry development (see e.g. Huang and Wu, 2007; Mathews et al., 2011; Pueyo et al., 2011; Walz and Delgado, 2012). A number of other studies use aggregate R&D and patent statistics both to assess the underlying processes of learning and whether innovative capabilities have developed at the industry level (see e.g. Walz et al., 2008; Tan, 2010; Walz and Weidemann, 2011; Dutch and Sharma, 2012; Wu and Mathews, 2012). This work therefore often misses potential intra-industry differences and firm-level specifics. Moreover, the economic indicators used only indirectly assess learning as an output of technological efforts. With notable exceptions, e.g. Lewis (2007, 2011), Mizuno (2007), Marigo (2009), Marigo et al. (2010), few empirical studies based on firm-level data have undertaken in-depth, longitudinal studies of learning and accumulation of innovation capabilities in individual firms.

One important question concerns the critical factors that underlie differences in the accumulation of innovation capabilities at the firm level. This has critical implications for understanding how foreign technology imports, and interactions between indigenous firms and international technology owning firms, might contribute more broadly to building low carbon innovation capabilities in developing countries and thus how policy and practice might target such capability building. One potential factor that might underlie inter-firm variance in capability building is the nature of the learning mechanisms individual firms employ to develop their in-house technological capabilities. This paper therefore sets out to explore the extent to which the use of different learning mechanisms can explain inter-firm differences in the accumulation of technological capabilities. This question will be explored by examining the dynamics of firm-level learning in relation to boiler manufacturing in the biomass power equipment industry in Malaysia from 1970-2011.

The paper is structured as follows: Section 2 develops the conceptual framework Section 3 sets out the methodology; Section 4 introduces the empirical context before, the main findings are presented in Section 5. The paper concludes in Sections 5 and 6 with a discussion of the results and drawing some conclusions.

2. CONCEPTUAL FRAMEWORK

This paper draws on two key theoretical distinctions made within the innovation studies literature to guide its empirical analysis. The first theorises a continuum of technological capabilities in developing country firms, from productive through to innovative. The second theorises a twofold categorisation of different learning mechanisms that firms might adopt and which might explain the accumulation of technological capabilities. The latter also facilitates elaboration of the theoretical underpinnings of assessing the role different learning mechanisms play in technological capability formation.

(a) *Accumulation of technological capabilities in latecomer firms*

This paper builds on the literature on technological learning and accumulation of technological capabilities in firms in developing economies – known as latecomer firms (see e.g. Amsden, 1989; Lall, 1992; Dutrénit, 2004; Bell, 2006). In this literature, firm-level "technological capabilities" are broadly defined as the resources needed to generate and manage technological change, including skills, knowledge, experience and organisational systems (Kim, 1997; Figueiredo, 2001). The accumulation of capabilities is thus conceptualised as a process whereby firms accumulate knowledge and skills over time that improve their ability to implement and handle technical change. Following Bell and Pavitt (1993), this paper makes a distinction between "innovation" capabilities and "production" capabilities. Production capabilities refer to the basic and routine-based capabilities necessary to produce industrial goods at different levels of efficiency, given various input combinations such as equipment, labour skills, product and input specifications, and the organisational methods and systems used. Essentially, such production capabilities represent the firms' ability to use, operate, and make small productive efficiency improvements in existing technologies and production systems. Innovation capabilities, on the other hand, denote the resources that firms need to create new, or to implement more substantial changes in products and product process organisation (Lall, 1992).

Production and innovation capabilities may according to Bell and Pavitt (1993; 1995) be considered to be at opposite ends of a continuum of sophistication of firms' innovative technological activities. Various studies have elaborated taxonomies to identify different degrees or levels of innovation capabilities of latecomer firms (see e.g. Katz, 1987; Lall, 1992; Ariffin, 2000; Dutrénit, 2000; Marcelle, 2004; Tacla and Figueiredo, 2006). These levels typically range from the basic operational production capability, at the lower end, towards more complex and advanced engineering and R&D-based activities, at the higher end, across various technical functions in the firm. As Bell (2007) and Plechero (2012) conceptualise, with an increase in innovative capability, firms are capable of mastering the generation of innovations with increasing degrees of novelty and complexity. At the lower end of the spectrum, innovations may be "new to the firm" and with increasing innovative capability, firms may generate innovations that are "new to the local industry" (or local market) and "new to the world" market (Fagerberg, 2005; OECD, 2005). It should be noted that in this context “innovation” can be taken to refer to both incremental and adaptive innovation, as opposed to simply radical (new to the world) type innovation. These former types of innovation, which may involve adapting technologies (including designs and organisational practices) to local contexts or incrementally improving technologies to move towards the technological frontier, are often of far more relevance in a developing country context (Mani and Romijn, 2004).

Building on this distinction between productive and innovative capabilities, a typology for assessing technological capability accumulation is presented in Table 1. It should be noted, however, that, as Bell and Figueiredo (2012) argue, the boundary between production and innovation capabilities is often fuzzy and not straightforward. Whereas other taxonomies, such as those elaborated in Ariffin (2000) and Figueiredo (2001), comprise indicators to assess the level of technological capability across a number of technical functions in the firm (such as process, product, equipment, or investment-related), this paper focuses exclusively on the product side. In the context of the case study of boiler manufacturing, this conceptualisation encompasses vital boiler and power plant components such as the grate, super-heater, economiser, fuel pre-treatment and fuel feeding system, as well as the complete power plant design and related engineering.

Table 1. *Typology of levels of technological capabilities in boiler supplier firms*

	Levels of technological capability	Product-related indicators
Innovative technological capabilities: Capabilities to generate and manage technological change	**(6) Advanced innovative capability**	-World leading in new boiler engineering and innovation based on cutting-edge research -Substantial number of highly specialised and internationally recognised R&D personnel -Systematic and continuous patenting of boiler design innovations that are "new to the world market"
	(5) High intermediate	-Own development of computer modelling and automation systems in project design engineering systems -Ongoing substantial independent R&D and engineering on new world class boiler system designs (close to the international innovation frontier) -Engaging in joint ventures and strategic alliances with leading foreign international firms and universities
	(4) Intermediate innovative capability	-Establishment of design engineering departments to undertake product-related R&D or substantial expansion of existing engineering staff -Product development certification (e.g. ISO 9001) or similar formalised qualifications -Continuous development of new product designs based on own research for local or regional markets -Establishment of collaborations with domestic research institutions and universities on basic R&D in new products
	(3) Basic innovative capability	-Systematic and planned routines to enhance boiler plant performance (improved project engineering design) with existing engineering staff -Acquiring designs that are new to the domestic market and using this to develop new products (e.g. from licensing new technology) -Significant modifications to existing designs and/or engaging in products that are completely "new to the local market and economy" -Generation of significant price-performance optimisation improvements compared to local/domestic competitors
	Boundary between production and innovation capabilities	
Routine production capabilities: Capabilities to use and operate existing technology	**(2) Extra basic operating capability**	-Outsourcing production of key components and the integration of these in the overall boiler plant design outlay -Minor adaptation in existing design specifications and small incremental improvement in boiler performance -Modifications of existing designs to generate products that are "new to the firm"
	(1) Basic operating capability	-Manufacture of standardised boilers and small-scale power plants according to fixed design specifications -Routine quality and control to maintain existing standards (ongoing and final inspection) -Own production of vital boiler pressure part components (e.g. pre-heaters, economisers, grates, furnaces, tubes, etc.) -Awarded international certification (e.g. ISO 9002, ASME codes, LRQA, BS2790)

Source: Adapted from Lall (1992), Ariffin (2000, 2010), Dutrénit (2000), Figueiredo (2001), Viotti (2002), Ariffin and Figueiredo (2004), Tacla and Figueiredo (2006), Bell (2007).

(b) *Learning mechanisms*

Bell (1984) distinguishes between two types of learning in relation to developing innovative capability in latecomer firms. The first type concerns doing-based learning that automatically and costlessly accrues from the continuation of well-established production activities, which through the implementation of minor changes may incrementally enhance the productive efficiency of a firm over time. Such efficiency improvements arise as passive by-products over time from the execution of standardised production tasks (Malerba, 1992). According to Bell and Pavitt (1993), this mainly experience-based learning may enhance the firm's production capabilities, but provide limited stimulus to increase the innovation capabilities of the firm to manage technology and implement technical change. In contrast, the second type of learning is conceptualised as involving more active and purposive investments in learning activities that improve the ability of firms to carry out in-house changes in production process organisation and products (Scott-Kemmis and Chitravas, 2007). Learning in the second sense thus requires conscious, costly, and concerted efforts through the allocation of necessary financial and human resources with the explicit purpose of building innovative capabilities. Following Bell and Figueiredo (2012), this paper focuses on learning understood in the latter sense - as deliberate processes by which additional technical skills and knowledge are acquired by individuals, and through them by organisations, potentially varying according to how explicitly deliberate these processes are and how much time and money is invested in them.

Within this definition of learning, this paper makes use of the framework developed in Figueiredo (2001, 2003) to conceptualise different mechanisms through which such learning might be pursued, and to assess the role of these mechanisms in firms' accumulation of technological capabilities. While the sources firms actively utilise to acquire and generate new knowledge may take various forms, this paper conceptualises learning as the acquisition of knowledge from two distinct learning processes: intra-firm learning and externally-mediated learning.

Intra-firm learning processes involve the acquisition of new knowledge from various sources within the firm. These internal learning processes comprise formalised and purposive activities that take place by engaging in systematic and continuous improvements of production organisation, products, and equipment. For example, involvement in planned experimentation in new investment projects may give rise to "learning by changing" through the modification of equipment and machinery, particularly if this builds consecutively on accumulated experience obtained in different projects. Achieving the most effective learning outcomes in such new investment projects may, according to Kim (1997), be more likely if the learning process is proactively approached by conscious efforts to plan and manage how knowledge will be obtained and integrated into the organisation. Another example of intra-firm learning takes place in practical problem solving efforts in specific projects in the form of "trial and error learning". Different types of formal in-house training programmes, both course-based and on-the-job training of workers, supervisors, and managers (e.g. in product design routines) may also provide "learning by training" possibilities for employees. The generation of new knowledge may also derive from "learning by searching" activities through in-house technical efforts in firm laboratories, formal R&D divisions, design and engineering departments, and quality and control units (Jonker et al., 2006).

Externally mediated learning, on the other hand, involves a number of ways whereby knowledge is acquired and internalised into the organisation from sources outside the firm (Bell and Figueiredo, 2012). In this paper, particular attention is paid to learning processes facilitated through dyadic relationships between firms, as opposed to other types of external influences, such as linkages with local universities or recruitment of employees from sources outside the firm. These dyadic relationships may be through linkages with foreign firms in the form of licensing agreements, joint ventures, technology cooperation, technical assistance, strategic alliances, and other forms of commercial inter-firm relationships that transcend the local economy. By facilitating the acquisition, assimilation, and possible improvement of foreign technologies, such transnational inter-firm linkages may comprise important sources of "learning by interacting" with foreign, more technologically advanced partners (Amsden, 1989; Hobday, 1995; Mathews, 2006). Another source of externally mediated inter-firm learning may take place when firms interact with local competitors either through formalised ventures, such as project partnering, or from non-formal channels such as "learning by imitation and copying" and local labour turnover. Such knowledge spillovers across firms in a local industry or economy may constitute a key (external) learning source for latecomer firms (Kesidou and Romijn, 2008).

This paper focuses on the extent to which firms make use of the different learning mechanisms introduced above in order to build innovative capabilities. Following Figueiredo (2001), attention is also paid to the *intensity* of management *effort* and financial commitment devoted to utilise a given source of learning, which Kim (1997) and Mathews (2006) also stress as an important determinant of technological capability building. These key characteristics of learning mechanisms, as operationalised in this paper, are illustrated in Table 2.

Table 2. *Typology for assessing learning mechanisms utilized by firms in developing technological capabilities.*

	Type of learning mechanism	
	Intra-firm	**Externally mediated**
Different learning mechanisms used by firms:	Presence or absence of processes for acquiring knowledge through internal activities	Presence or absence of processes for acquiring knowledge locally and/or abroad
Intensity of efforts devoted to utilise a given learning mechanism:	Level of persistence and human and financial resources devoted to leverage learning from in-house efforts	Level of persistence and human and financial resources devoted to leverage learning from external sources

Source: Adapted from Figueiredo (2001; 2003)

(c) *The importance of different learning mechanisms*

Based on the conceptualisation above, one may distinguish between learning mechanisms that are either internal or external (local or foreign) to the firm (Bell and Figueiredo, 2012). Viotti (2002) stresses that technological learning in latecomer firms is largely confined to the absorption of existing technologies acquired from foreign, more technologically advanced firms. This recognition of the importance of external, foreign sources of knowledge is encompassed in various conceptual frameworks addressing the dynamics of technical change in developing countries. In the literature on capital investments by multinational firms in developing countries, for example, much effort has been devoted to analysing the knowledge spill-over effects of foreign investments in local industries (see e.g. Blomström et al., 2000; Saggi, 2002). In a related body of literature, the dissemination of knowledge from multinationals to local producers inserted in global production networks has been extensively examined (Ernst and Kim, 2002). Similarly, the global value chain perspective has placed equal emphasis on foreign sources of learning, and devoted particular attention to understanding how lead firms govern the flow of knowledge and thereby the prospects for industrial upgrading amongst local suppliers (Gereffi, 1999).

With regard to local sources of learning, other analytical frameworks have accentuated the importance of local knowledge systems in latecomer firms' technological capability building (Bell and Albu, 1999). A lot of the literature on industrial clusters in developing countries, for example, addresses knowledge flows occurring, inter alia, through interactions among local competitors, user-producer relations, industry-university linkages, new firm creation, and labor mobility (Schmitz and Nadvi, 1999). In another body of the literature on innovation systems in developing countries, the main research interest concerns the institutional structures that enable knowledge flows among various actors at the national, sectoral, or regional level (Malerba and Mani, 2009; Lundvall et al., 2009).

Other frameworks have emphasised the important role of firms' internal strategic intent to invest in activities aimed at generating new knowledge from intra-firm sources (Xie and White; Scott-Kemmis and Chitravas, 2007). In the international business literature, for example, scholars adopting a resource-based view of the firm have focused on the essential role of increasing the internal human capital in latecomer firms as a central element of technological capability building (Mathews 2002). In a related literature addressing the development of absorptive capacity in latecomer firms, the key role of internal R&D investments and the cumulative nature of technological capability formation has been emphasised (Cohen and Levinthal, 1990).

While this short discussion by no means provides an exhaustive review of the treatment of the role of internal, local, and foreign sources of learning in various bodies of literature, it illustrates that these learning mechanisms are often treated separately. However, since it may be useful to consider these, at least potentially, as complementary (rather than alternative) sources of technological capability building, some recent studies have highlighted the importance of assessing how firms use different combinations of such learning mechanisms (see e.g. Giuliani et al., 2005; Kesidou and Romijn, 2008; Fu and Gong, 2011; Fu and Zhang 2011; and Li, 2011). Building on these studies, this paper examines which specific combinations of learning mechanisms firms utilise as complementary composites or bundles of learning mechanisms, thus providing a basis for examining the consequences of these firm-specific patterns for the levels of technological capability achieved.

3. EMPIRICAL CONTEXT

Together with Indonesia, Malaysia is the largest producer and exporter of crude palm oil and derived products in the world. Since the 1970's, Malaysia's production output and area under palm oil cultivation increased exponentially, leading to a concomitant increase in palm oil biomass waste. Compared to other residual biomass resources in Malaysia, such as rice husk or sugarcane bagasse, the electricity potential from utilising palm oil biomass waste is by far the largest - around 2700 MW in 2007 (Chua et al., 2011). Among these biomass waste by-products, empty fruit bunches (EFB) are the most abundantly available and lowest cost. At least until the beginning of the 1990's, this resource was left largely unutilised in the palm oil industry except for mulching purposes. Owing to the anaerobic decay of EFB and palm oil mill effluent (POME), palm oil mills generate substantial methane gas emissions which have 20 times the warming potential of carbon dioxide as a greenhouse gas.

In palm oil mills, the usual waste management practice involved the utilisation of palm kernel shells (PKS) and mesocarp fibres in cogeneration plants to meet the internal process steam requirements owing to a higher calorific value compared to EFB. These conventional captive power plants were deliberately designed inefficiently in order to burn as much biomass waste as possible since the potential energy from utilising PKS, mesocarp fibres, and EFB was much larger than required by mills. Besides mulching, EFB was mainly left to decay in open landfills and stockpiles since it was difficult to utilise EFB directly in boilers owing to a high moisture, chlorine, and alkali (silica) content. Consequently, limited experience was generally accumulated in the local boiler industry with regard to utilising EFB efficiently for energy generation, particularly for modern, large-scale, and high-efficient combined steam and electricity power plants.

However, since the 1990's a number of factors contributed to conducive conditions for investments in renewable energy in general and EFB-fired power plants in particular (Hashim and Ho 2011). This created demand for EFB-fired power plants in Malaysia, opening new market opportunities for local boiler supplier firms. This market demanded fundamentally different products in terms of scale and efficiency than normally required in the conventional inefficient and small-scale cogeneration plants in palm oil mills. In contrast to the old, typically low pressure and low temperature palm oil mill boilers, the new market increasingly demanded efficient, high pressure and high temperature boilers in large-scale power plants. In order to compete in this market and meet this demand, Malaysian boiler supplier firms were, due to a lack of previous experience, forced to engage in concerted learning efforts and accumulate technological capabilities to improve their ability to implement technological changes. This dynamic setting thus provides a suitable context to examine the extent to which individual firms used different learning mechanisms and whether this influenced technological capability formation.

4. METHODOLOGY

This paper uses qualitative data from in-depth, semi-structured interviews with key employees in the eight Malaysian boiler and power equipment supplier firms which had achieved the strongest positions in the emerging market for palm oil biomass waste-to-energy power plants in Malaysia (see also Hansen, 2011, 2013; Hansen and Nygaard, 2013, 2014). Data was collected during successive field studies in 2007, 2010 and 2011 and supplemented with documentary material (such as archival firm statistics, firm websites, and industry reports) as a form of method triangulation to ensure validity (Meijer et al., 2002). The eight firms were identified by consulting industry experts in Malaysia, and using a snowballing method to consult with competitors and customers, to ascertain which firms had supplied boilers to the majority of EFB-fired power plants constructed in Malaysia between 1990-2011. Key characteristics of these firms, which have been anonymised in this paper owing to confidentiality concerns, are presented in Table 3. Using the triangulation by data source method, interviews were undertaken with lower and higher ranking employees with shorter and longer-lasting positions in each firm, including former employees. In total, thirty in-depth interviews were conducted and digitally recorded, transcribed and analysed. In advance of the data collection process, an identical interview questions protocol was prepared, which was used across the interviews conducted (see Appendix).

Table 3. *Key figures on the firms analysed*

	Production personnel	Engineering and Administration personnel	Year established	Ownership
ENCO Systems	15	20	1975	Malaysian owned
Vyncke East Asia	0	30	1985	Foreign subsidiary
Mackenzie Industries	40	50	2005	Malaysian owned
Boilermech	70	58	2005	Malaysian owned
Vickers Hoskins	40	20	1978	Malaysian owned
Mechmar Boilers	80	15	1972	Malaysian owned
Advance Boilers	40	32	1993	Malaysian owned
Petra Boilers	12	25	1974	Malaysian owned

(a) *Concept operationalisation and data acquisition*

(I) *Variety and intensity of learning mechanisms used by firms*

To gain insights into the variety of learning mechanisms used by individual firms in their technological capability building efforts, interviews were conducted using the following guidance:

1. Interviewees were introduced to the conceptual distinction between external and internal types of learning mechanisms and given examples of these.
2. Interviewees were asked to use this categorisation throughout the interviews to elaborate which learning mechanisms, and specific combinations of them, they predominantly utilised during their involvement in EFB-fired power plants.

3. To guide their evaluation of learning mechanisms, interviewees were asked which learning mechanisms they considered most important in increasing their firms' ability to handle the engineering-related activities in the design and construction of EFB-fired power plants.
4. Interviewees were requested to substantiate the nature of identified learning mechanisms in further detail, including follow-up questions on what and how specific employees learned from different sources and how this learning process became manifested in concrete terms in the plants constructed.

This information fed into a subsequent round of interview questions that addressed the intensity of efforts devoted to utilise specific learning mechanisms using the following guidance:

1. Interviewees were asked to describe to which extent, and at which level of persistency, the management allocated financial and human resources to extract knowledge from a given source.
2. In interviews with firm managers, they were asked specifically about the level of attention and priority given to acquire new knowledge.
3. Additional probing questions were use to elicit detailed information, including the number of man-hours spent on intra-firm trial and error efforts (e.g. from on-site problem solving), internal R&D investments, and the level of continuity of resources devoted to searching for and leveraging knowledge from foreign technology suppliers and/or local competitors.

(II) *Levels of technological capabilities achieved by firms*

Before conducting interviews in Malaysia, the levels and related indicators on technological capabilities detailed in Table 1 were first validated with firms in Denmark to see if they made sense to people working in the biomass boiler industry. Validation was based on consultations with five recognised Danish leaders in biomass boiler technology, Babcock & Wilcox Volund, Danstoker, Aalborg Boilers, SEM A/S and B&W Energy. This confirmed that the indicators in Table 1 made sense to people working in the industry and was therefore deemed appropriate for application in the fieldwork in Malaysia.

Interviews with the Malaysian boiler manufacturing firms applied the following guidelines to assess relative levels of technological capabilities:

1. Interviewees were first asked to elaborate on the technological milestones they considered most important during their firms' involvement in EFB-fired power plants.
2. To facilitate discussion interviewees were provided with examples that might have been associated with such milestones, such as the achievement of significant plant performance improvements, major design modifications, or specific landmark projects.
3. Interviewees were explicitly informed that these milestones should reflect a manifestation of their firms' increased level of skills to handle and improve their EFB-fired power plant technology.
4. Interviewees were subsequently shown an overview of the indicators described in the second column of Table 1 and asked a series of questions addressing the indicators in ascending order.
5. Using technological originality as a main indicator of the level of technological capability achieved by the firms, the interviewees were asked to describe which kinds of technical changes that they implemented during their involvement in

EFB-fired plants, explicitly distinguishing between "no changes" from those that were "new to the firm", "new to local market", and "new to the world market". To obtain this information, interviewees were asked about the type of boiler technologies supplied by the firms, including when and if they introduced new designs or products, and whether these were distinctly different from the existing ones in the local market.

6. As a secondary indicator, additional questions addressed whether the technical changes implemented by the firms were associated with relatively minor or more significant price/performance ratio improvements compared to similar plants constructed in Malaysia.
7. As a third indicator, interviewees were asked about product quality certifications acquired relating both to design and product standards.
8. To triangulate data on technological originality gathered from individual interviews, data were compared across interviewees and with other sources of data, such as firms' archival records and industry reports.

(b) *Categorisation of the firms*

Data collected from the interviews were analysed in relation to two key issues identified in the literature reviewed in Section 2 above: I. Variety of learning mechanisms employed by the firms and the intensity of efforts devoted to leverage knowledge from these; II. Levels of technological capability achieved.

(I) *Variety and intensity of learning mechanisms used by firms*

Learning mechanisms employed by the firms were categorised according to the importance ascribed to particular learning mechanisms by the interviewees in relation to their firms' technological capability building efforts. Explanations given by interviewees of the sources relied on to gain new technical insights and overcome concrete problems during involvement in successive projects provided evidence on the nature of intra-firm and externally mediated learning mechanisms employed. A given learning mechanism was interpreted as present if it was emphasised as having played an important role by the interviewees and was interpreted as absent if they did not ascribe importance to a particular learning mechanism.

The intensity of efforts devoted to different learning mechanisms were categorised based on interviewees' responses according to a continuum from short-term (one-off) efforts and the allocation of limited resources to utilise different learning mechanisms, to more persistent (longer-term) efforts with higher levels of devoted resources.

(II) *Levels of technological capabilities achieved by firms*

Classification of technological capability used an analytical coding of interviewees' responses to questions on types of technical changes implemented during firms' involvement in EFB-fired power plants. Key indicators included level of originality (or novelty) of technological changes, which ranged from minor adjustments of existing boiler sub-components (possibly as part of repair and maintenance activities) towards more profound, and possibly entirely new, reconfigurations of the entire power plant design arrangement (involving new products and engineering solutions) (see also Plechero, 2012). A secondary indicator of changes in technological capability focused on price/performance improvements achieved. The coding process also applied the other indicators in Table 1. Firms did not have to comply with all of the indicators to be placed within a given category level.

To illustrate the application of the coding process in practice, if interviewees stressed that they more or less continued to use their pre-existing boiler design drawings and standardised products without introducing any changes or achieving performance improvements, they were classified at the lowest level of technological capability, the "Basic operating capability" level in Table 1. Firms that had undertaken minor and incremental modifications to existing designs that were "new to the firm", including small improvements in plant price/performance ratios, were classified as having reached the "Extra basic operating capability" level. The "new to the firm" classification was interpreted as evident in cases where a firm introduced a new product or design that was already available from competitors in the local market. Firms that had introduced technical changes that were "new to the local market", including alternatives that were markedly different from existing designs used by their local competitors, were categorised as having reached the "Basic innovative capability" level. Another indicator used to determine whether firms achieved this level, involved assessing whether such changes encompassed significant plant price/performance ratio improvements compared to the plants constructed by their competitors.

(c) *Identification of patterns across firms*

Following the analytical coding procedures related to the individual firms described above, subsequent analysis focused on identifying similar patterns across the firms in the variety and intensity of learning mechanisms used and the level of technological capability achieved. This categorisation employed a qualitative assessment, which focused on identifying similarities in interviewees' responses within each of these themes using the tabular (cross-sectional) coding method suggested in Miles and Huberman (1994). To provide a practical example of this, firms relying mainly on license agreements or joint ventures were categorised as having utilised technology partnerships with foreign partners as a particular form of external learning.

5. RESULTS

The analysis led to the classification of the eight firms into the three main groups detailed in Table 4. Each group shared common features in terms of the learning mechanisms employed, the level and intensity of efforts devoted to leverage knowledge from these, and the levels of technological capability achieved. To provide a more detailed overview of the characteristics shared across these groups, a detailed description of one firm illustrative of each group is provided below – Alpha for Group 1, Epsilon for Group 2, and Zeta for Group 3.

Table 4. *Key findings on learning patterns and levels of technological capability achieved*

	Intra-firm learning		**Externally-mediated learning**		**Level of technological capability achieved**
	Presence / absence	**Level of intensity**	**Presence / absence**	**Level of intensity**	
Group 1 (ENCO, Mackenzie, Vyncke)	"Learning through planned experimentation"	Significant	"Learning from interacting with foreign technology partners"	Significan t	"Basic innovative capability"
Group 2 (Vickers, Boilermech)	"Learning from trial and error efforts"	Low	"Learning from imitation of local competitors"	Significan t	"Extra basic operating capability"
Group 3 (Mechmar, Advance, Petra)	"Learning from trial and error efforts"	Low	Absent	Absent	"Basic operating capability"

(a) *Three illustrative firm representations*

(I) *Representative illustration of firms in Group 1*

Since its initiation in 1975, Alpha primarily installed and undertook service on imported industrial boilers and since 1992 manufactured and installed small-scale wood-fired and industrial gas/oil-fired boilers under a license agreement with the Danish company Danstoker A/S (Hansen, 2011). However, in 1998, Alpha decided to focus entirely on the emerging market for EFB-fired power plants. According to interviews with firm managers, one of the ambitious aims of Alpha was to become an energy service company (ESCO) supplying steam and/or electricity to industrial users from EFB-fired power plants. As the main investor and risk taker, Alpha had a strong strategic interest in continuously optimising their plants, which pushed the firm to devote sustained financial and human resources to their ongoing learning efforts.

Alpha proactively recognised a need early on to acquire new knowledge from different sources and paid particular attention to establishing relations with foreign technology partners. It engaged in a license contract in 1997 with the parent company of Danstoker at that time, Volund A/S, to manufacture and install a large-scale and high-efficiency biomass plant designed to utilise EFB and other fuels with high moisture content. According to interviewees, Alpha initially aspired to acquire access to the basic boiler design through the license agreement with Volund, which firm managers considered would address their limited technological expertise. As a main learning strategy, Alpha's management wanted to learn as much as possible from the relationship with Volund and accumulate knowledge over time through planned experimentation in successive plants on a project-by-project basis. After engaging in its first EFB-fired power plant in 2000, in 2004 Alpha introduced a new vibrating and water-cooled (inclining) membrane grate system in an EFB-fired and grid-connected power plant in Malaysia under the license agreement with Volund. This type of system, which included fully automatic feeding, had not previously been constructed in Malaysia. Subsequently, Alpha sold around seventeen of these boiler units to customers in the palm oil industry in Malaysia and Thailand.

According to longstanding managers in Alpha, the license partnership with Volund enabled employees from Alpha to access a highly skilled pool of expertise and learn about critical elements of advanced boiler designs, including vital calculation methods. This externally mediated learning by interacting process occurred during on-site plant visits, overseas training, and through technical assistance. This learning process was particularly intensive in the period after the second plant was constructed in 2004 when the management in Alpha was committed to persistently devoting efforts and resources to leverage learning through regular interaction and communication between employees in the respective firms. Through this interactive relationship with Volund, Alpha 's employees reached a sufficient level of knowledge to enable Alpha to subsequently manufacture, install, and further develop similar plants independently.

Regarding intra-firm learning, Alpha recognised a need for pre-treatment of EFB to reduce moisture content and fibre length, which were found to be critical determinants of boiler performance. To overcome this challenge, Alpha’s learning strategy was to gradually develop a new EFB pre-treatment system through planned experimentation and learning by changing in successive plants. Alpha employees approached this learning process by continuously optimising plants by adding and replacing equipment (such as shredding and drying machinery) and subsequently integrating discovered solutions in new plants. This systematic experimentation process involved the introduction of a new automatic fuel feeding system, which was better suited to EFB than the original Volund design. Volund’s design was evidently modified by Alpha in their efforts to utilise EFB, including introduction of a new furnace de-ashing system and a reconfiguration of the primary and secondary fans outlay. This pre-treatment system had not previously been used in Malaysia and was therefore new to the boiler industry and local market.

Owing to the low ash melting point of EFB, another persistent problem concerned formation of clinkers on heat surfaces in the boiler, a significant technical challenge which increased with utilisation of a higher percentage of EFB in the boiler. Attempts to circumvent clinker formation focussed on efforts to optimise the integrated furnace water cooling system. In addition, learning efforts were devoted to optimising the boiler control system by continuously adjusting critical parameters in plant performance, such as those related to air inlet velocity and fuel feeding operations. Throughout their engagement in EFB-fired power plants, Alpha persistently devoted significant financial and human resources to internal learning efforts in order to solve the multitude of challenges experienced. Thus, it appears that Alpha utilised a unique combination of (externally mediated) learning from interacting with a foreign technology partner and (intra-firm) learning by planned experimentation, both of which were characterised by a high level of intensity of efforts. The case of Alpha thus illustrates the complementarity between the use of specific types of external and internal learning mechanisms.

The interviews suggested the ability of Alpha to implement and handle technical change in EFB-fired power plants was significantly improved during their involvement with different plants. This resulted in substantial plant price/performance ratio improvements over time compared to Alpha’s domestic competitors. In addition, Alpha's employees were independently able to design a fuel pre-treatment system that was new to the local industry and domestic market. With the introduction of a new automatic fuel feeding and optimised design outlay in this fuel pre-treatment system, Alpha was able to achieve a higher overall plant performance than by using the design initially acquired from Volund. This indicates that Alpha made some progress in moving from the basic level of routine-based production capabilities into more advanced stages of innovative technological capability. Based on the originality of the technical changes implemented by Alpha and the significance of the price/performance improvements made, Alpha could be considered to have progressed to the "Basic innovative capability" level in Table 1.

(II) *Representative illustration of firms in Group 2*

Since its establishment in the late 1970's, Epsilon mainly supplied boilers to the palm oil milling industry and to a lesser extent small-scale packaged gas and oil-fired boilers to various industries. Over a period of more than thirty years, the firm was, according to the interviews, able to achieve a large share in the market for palm oil mill boilers in Malaysia (around 30% in 2011). Managers at Epsilon suggested this was an outcome of the primary and longstanding strategy of the firm, which was to secure and enlarge its market position. In 2002, however, Epsilon's management decided to diversify activities and engaged in their first EFB-fired power plant at an existing palm oil mill in Malaysia. Subsequently, Epsilon was involved in the construction of five additional EFB-fired power plants.

At the outset of their engagement with EFB-fired power plants Epsilon apparently demonstrated limited recognition of a need to acquire new knowledge from different sources. During construction of the first plants, Epsilon's managers considered the existing boiler technology design, which inter alia comprised a conventional step grate and water-tube system, to be sufficient for utilising EFB. This design had previously been used in Epsilon's construction of boilers supplied for the palm oil milling industry, acquired initially in 1980 through a license agreement with a UK-based company. According to managers at Epsilon, the percentage of EFB utilised and the customer's required performance levels in the first EFB-fired power plants were both relatively low. Consequently, Epsilon only experienced minor operational problems in these plants. Later, Epsilon's management found additional changes to the existing boiler design were necessary to utilise a higher percentage of EFB at higher efficiency and performance levels in order to compete in this market. This led Epsilon to search for new sources of learning during subsequent projects. In contrast to Alpha and the firms in Group 1, Epsilon did not actively promote EFB-fired power plants to new potential customers. The engagement in these plants was, according to the interviews, mainly driven by direct demand from specific customers and was therefore not, as in the case of Alpha, an outcome of a deliberate strategy to learn through planned experimentation in successive plants.

The main learning strategy pursued by Epsilon was to rely primarily on learning from their local competitors though non-formal channels and internal efforts by modification of their pre-existing boiler designs. To learn from competitors, Epsilon's employees devoted significant time and resources to searching for information about the technological solutions that led to performance improvements, mainly in the plants constructed by Alpha and the other firms in Group 1. This was achieved through plant site visits, communication with industry contacts (including former employees), relations with customers, and hear-say. Apparently both plant owners and boiler technology suppliers attempted to prevent this information from being openly disseminated, for example by enforcing strict plant visiting regulations. According to interviews with firm employees, Epsilon's management came to the conclusion that EFB fuel pre-treatment systems, and, even more so, boiler water-cooling systems had contributed significantly to solving the clinker formation problem in other plants. Accordingly, employees from the engineering department in Epsilon concentrated efforts on developing a similar water-cooled grate system in an attempt to circumvent this generic problem. These internal efforts resulted in some learning through imitation, contributing to Epsilon subsequently developing a water-cooled grate design that was new to the firm. However, according to an interview with a representative of Epsilon's license partner, the design was relatively simple and did not work well. Epsilon's management also found that the design was not able to resolve the problems experienced and soon abandoned further development of this grate system. These relatively short-term internal efforts in Epsilon's engineering department were therefore undertaken with limited persistence.

Management subsequently decided to import a water-cooled vibrating grate from an internationally renowned supplier of biomass combustion technology (from the US) and to implement this system in later plants. Epsilon did not devote efforts to leverage learning through the establishment of a longer-term partnership or through closer interaction with this grate supplier company. Moreover, according to interviews with managers, Epsilon did not actively seek to utilise the relationship with its existing license partner in its learning efforts. Since it proved problematic for Epsilon to incorporate the vibrating grate in the firm's existing power plant design, some internal trial and error learning efforts were employed. These problem solving efforts concerned a number of issues related to malfunctioning of the draught fan systems and water feeding pumps. These challenges were more profound than initially foreseen and resulted in financial losses, so Epsilon was hesitant to engage in further EFB-fired power plants.

The case of Epsilon depicts a particular combination of the use of (externally mediated) learning by imitation and (intra-firm) trial and error efforts to develop and integrate a new grate system into their existing designs. This unique combination was different from the specific composition of internal and external learning mechanisms used by firms in Group 1. From interviews with Epsilon's managers, it appears that many problems remained unresolved during their involvement in EFB-fired power plants and Epsilon only recently made progress in overcoming some of these challenges. Epsilon was only able to achieve small price/performance ratio improvements through minor, incremental modifications to existing design specifications. Epsilon also managed to develop a water-cooled grate design that was new to the firm by imitating its domestic competitors, although this system did not perform well and further development was quickly abandoned. Thus, the ability of the firm to implement and handle technical change was only advanced to a limited extent commensurate with the second level of production capabilities (the "Extra basic operating capability" level in Table 1), but not to have progressed further into developing innovative capability.

(III) *Representative illustration of firms in Group 3*

Zeta was established in 1972 and initially involved mainly in installation and servicing of imported boilers. From the late 1970's, Zeta began fabricating packaged fire-tube boilers under a license agreement with a UK-based company and later in 1982 began producing water-tube (fixed grates) boilers for the palm oil industry under another license agreement. This mainly followed the general development of the Malaysian boiler industry. When demand for larger capacity boilers with higher levels of automation increased during the 1990's, Zeta developed a moving grate system to meet these requirements on the basis of their pre-existing boiler designs. Notwithstanding these minor incremental modifications, the basic boiler design in Zeta has remained largely unaltered over the last 15 years.

Zeta and the two other firms in Group 3 focused mainly on the market for conventional packaged gas and oil-fired boilers to various industries. However, according to interviews with managers in Zeta, management increasingly recognised a need to diversify activities to avoid becoming overly dependent on this market. This led to Zeta engaging in their first EFB-fired cogeneration plant in 2002 at an existing palm oil mill. The plant utilised a relatively low percentage of EFB in the fuel mix (around 30%) and the customer required a low performance level. The second cogeneration plant Zeta constructed was similar to the first, although it utilised a higher percentage of EFB in the fuel mix. In both plants, a boiler was used which had previously been supplied to customers in the palm oil milling industry. According to interviews with engineering employees at Zeta, these plants only gave rise to minor difficulties, which required some problem solving efforts at the plant sites. They attempted to circumvent these problems mainly through further modification of the moving (step) grate system via relatively short-term internal trial and error based learning efforts.

Zeta’s main learning strategy during involvement in these plants was to utilise their pre-existing boiler designs, which were considered suitable for a larger fraction of EFB than normally required in palm oil mills. Since the plants constructed by Zeta and the firms in Group 3 generally utilised a relatively low percentage of EFB in the fuel mix, typically around 30-40%, they were able to use the pre-existing conventional boiler designs without many problems and without much technical effort. In contrast to the plants constructed by firms in the other two groups, Zeta also only retrofitted existing steam generation plants in palm oil mills, not in plants primarily designed for electricity generation, which would have required additional design changes. Thus, Zeta did not recognise a need for new sources of learning in their efforts to overcome the minor challenges experienced. As an example, although an external engineering consultant provided some technical assistance to engineers in these projects, Zeta did not purposely seek to leverage learning from this source to any great extent. Zeta’s management also did not attempt to establish new relationships with external technology partners in their learning efforts.

Although Zeta experienced some minor problems during involvement in EFB-fired cogeneration plants, the challenges experienced were largely overcome by relying on their existing technology. The necessity of acquiring new knowledge and engaging in concerted efforts to overcome these problems were consequently limited, which resulted in the allocation of only a very limited amount of time and financial resources to problem solving. Essentially, therefore, Zeta continued to carry out their previous, routine-based production activities without many changes or additional learning efforts. Accordingly, Zeta did not achieve any price/performance ratio improvement. The manufacture of boilers and construction of power plants was undertaken according to pre-existing and standardised design specifications. Zeta can therefore be considered to have remained at the lowest level of technological capabilities, the "Basic operating capability" level in Table 1.

6. DISCUSSION

(a) *Learning and technological capability formation*

Existing studies of learning and technological capability formation in cleantech industries in emerging economies pay little attention to micro-level dynamics, despite the highly firm-specific nature of such processes (Lall, 1992). The analysis in this paper suggests that learning mechanisms employed by individual firms plays a critical role in the level of technological capability achieved, a finding that is likely to resonate across other industrial sectors beside cleantech. As illustrated through the case of Alpha, technological capability building was most pronounced where firms dedicated significant, sustained resources to a specific combination of learning from interacting with foreign technology partners and intra-firm planned experimentation activities.

These findings are consistent with previous studies on development of wind and solar industries in China and India, where foreign connections were also found to constitute important sources of learning (see e.g. Lewis 2007, 2011; Mizuno, 2007; Marigo et al., 2010). At a more general level, this supports the argument put forward in Kim (1997), Mathews (2002), and Bell and Figueiredo (2012) that significant advances in technological capability formation in latecomer firms is often related to learning through networks of foreign and more advanced technology partners. However, following Fu and Gong (2011), this also speaks to a broader discussion about internal (or indigenous) learning and innovation, on the one hand, versus foreign technology, on the other hand, as the main sources of technological capability formation in latecomer firms (see also Fu and Zhang, 2011). In this paper, Alpha and the firms in Group 1 were required to engage in concerted internal efforts to adapt and modify acquired foreign technology to improve its performance. Alpha, for example, not only devoted substantial resources to leverage learning from its foreign license partner, but also to its own efforts to engage creatively with the original design. Therefore, as Li (2011) argues, foreign sources of advanced technology will only enhance latecomer firms' levels of technological capability to the extent that simultaneous concerted investments are made in internal learning efforts. Thus, as the case of Alpha illustrates, and in line with Fu et al. (2011), rather than understanding technological capability formation as driven either by foreign or internal sources, these may more appropriately be considered as complementary drivers.

The more limited progress made by firms in Group 2 in building technological capabilities through a combination of imitating local competitors and internal (engineering) trial and error focused on modification of existing grate designs suggests at least three further insights. First, as Kesidou and Romijn (2008) note, learning opportunities available from local knowledge systems may provide an important stimulus for technological capability building in latecomer firms (see also Bell and Albu, 1999). Among such learning sources, Chen (2009) particularly stresses the role of inter-firm interactions in the form of informal knowledge spill-over among local competitors. As Mathews (2006) argues, however, since latecomer firms typically operate in isolation from world centres of science and innovation and sophisticated technology markets, the reliance on local learning sources may comprise a key barrier to technological capability building. This argument is further devolved in Plechero (2012), who emphasises that knowledge diffusion among local competitors may only enable firms to progress production capabilities - in order to reach more advanced levels of innovation capability, additional, complementary sources of learning may be required. As illustrated by Epsilon, the empirical findings of this paper appear to corroborate this proposition since the firms in the Group 2 were not able to advance beyond the level of production capability. Notwithstanding this, owing to substantial resources devoted to imitating local competitors, the use of this learning mechanism did constitute an important stimulus for the technological capability improvement that did occur in the two firms in Group 2. However, the lack of resources devoted to engaging (concomitantly) in internal learning efforts may also have hindered the attainment of higher levels of technological capability.

Second, and relatedly, since the learning efforts of the two firms in Group 2 focused on imitation of plants constructed by firms in Group 1, this speaks to a broader discussion on local spill-over effects of technologies acquired from foreign sources (Fu et al., 2011). In the literature on inward foreign direct investments in emerging economies, the extent local firms benefit from knowledge spill-over effects is often discussed (Blomström et al., 2000). Benefits might be in the form of learning opportunities provided by exposure to new, more advanced technology and local diffusion of technological knowledge. As Saggi (2002) emphasises, technology owners often try to mitigate against unintended local spill-over of proprietary technological assets, which tends to reduce local knowledge diffusion. This paper corroborates this finding as firms in Group 1 strove to hinder knowledge from being openly disseminated, e.g. by enforcing strict visiting rules and regulations at plant sites. The diverging interest between technology owners and imitators may therefore comprise a central limitation in learning by imitation as opposed to learning through more formalised partnerships with foreign technology partners. It should, however, be noted that learning by imitation might be critical in the infant stages of technological capability building, but becomes less important as firms progress towards higher levels of innovative capability (Kim, 1997; Chen, 2009; Lema and Lema, 2012).

A third interesting finding concerns the nature of firms in Group 2's learning through relationships with foreign technology partners. As illustrated by Epsilon, although relationships were established with more advanced technology suppliers, limited efforts were devoted to leveraging learning from these sources. Epsilon could, for example, have achieved this by establishing a longer-term relationship with its water-cooled grate supplier and/or by extracting new knowledge from its established license partnership. The lack of technological capability building through learning from foreign partners in this case were therefore not caused by a lack of opportunity, but rather by a lack of strategic decision to dedicate resources to pursue such learning. As emphasised by Figueiredo (2001, 2003) and Mathews (2006), the extent to which such external linkages with foreign firms facilitate learning and technological capability building is strongly related to the persistence and resources (the intensity of efforts) devoted to utilising such learning opportunities. This paper seems to corroborate this argument.

The firms in Group 3 relied exclusively on internal sources in their learning efforts and, during their involvement with EFB-fired power plants, did not progress beyond the basic and lowest level of technological capability in Table 1. According to Edquist (1997), learning and innovation in firms rarely take place in isolation, but occurs through complex and varied interactions with the different actors and organisations in their external environment. Thus, as

Bell (1984) argue, latecomer firms relying exclusively on their own resources and internal learning efforts are likely to have a hard time building technological capability. This is attributed, among other things, to the widespread absence, under-prioritisation, and/or understaffing of in-house R&D resources in many latecomer firms, especially small and medium-sized enterprises (Mani and Romijn, 2004). The case of Zeta seems to illustrate these limitations of relying exclusively on internal learning efforts in technological capability formation. However, Figueiredo (2001) emphasises the need not to underemphasise the importance of building a minimum level of technological capabilities through internal efforts in latecomer firms. Cohen and Levinthal (1990) attribute this importance to the cumulative nature of technological capability building, which involves gradual increases in the efficiency of internal learning and associated increases in technological capabilities. Since the firms in Group 3 devoted very limited resources in their internal learning efforts, their ability and efficiency to appropriate additional learning remained limited (see Xie and White, 2004; Scott-Kemmis and Chitravas, 2007).

(b) Reflections on technological capability building and low carbon development

As flagged in the introduction, an emerging body of literature seeks to develop theoretical contributions of past work on technological capability building in the context of specific challenges relating to low carbon technology transfer to developing countries to mitigate future development-related carbon emissions (e.g. Mathews, 2007; Altenburg, 2008; Walz, 2010; Ockwell et al., 2008, 2010; Berkhout, 2012). Research in this area is, however, very much in its infancy – there is a lack of empirical evidence and a distinct lack of any comprehensive attempt at theorising technology transfer and indigenous innovation as part of broader low carbon development pathways (Ockwell and Mallett 2012). There are a number of areas where this paper's findings on the role of learning mechanisms and technological capability building in a specific cleantech industry in Malaysia suggests broader implications for both theory building and future empirical research covering a wider range of industrial sectors.

An initial focus for future research is to explore the applicability of the specific combinations and intensities of learning mechanisms identified by this and other papers within the context of other technologies, industries and countries. Low carbon energy technologies need to be researched across a spectrum of supply, network/infrastructure and end use technologies. But it is also important to explore them along the continuum of the innovation chain, from R&D, through demonstration, to widespread commercial availability. Specific risks and challenges apply at these different stages of maturity and their implications for learning and development need to be better understood (Ockwell et al., 2008). There is also a particular need to understand the role of learning mechanisms and technological capability development in lower and lower-middle income countries where existing levels of technological capabilities are likely to be low even for dealing with conventional energy technologies, let alone, newer, more efficient, low carbon technologies. This raises important questions as to what combinations of learning mechanisms are most appropriate in these contexts, and what firm based or public policy driven strategies are needed to encourage such learning and related capability building.

The internal efforts that firms employ to develop technological capabilities are currently understudied in existing studies on the evolution of cleantech industries in emerging economies (Mizuno 2007; Marigo, 2009). With notable exceptions (e.g. Lema and Lema, 2013), policy-oriented studies which have attended to the importance of technological capability building through low carbon technology transfer have also, to date, largely failed to analyse individual firm-level learning mechanisms, often relying on relatively crude typologies of technology transfer applied to large datasets of project proposals (Haites et al., 2006; Das, 2011). The historical, in-depth analysis applied in the current paper suggests one way of overcoming the methodological limitations of these other efforts. However, it raises difficult tensions with the urgency of providing sound empirical bases for designing climate and development policy.

Another weakness of the literature and policy thinking in this area is a tendency to conceive of technology transfer as constituting individual events, supporting the assumption that these events might somehow be scaled up to achieve more rapid diffusion of low carbon innovations in developing countries (Ockwell et al., 2010). This overlooks two important issues. Firstly, it fails to recognise the widespread adoption of low carbon technologies as the result of a *process* over time, involving both individual events of technology transfer and related processes of learning and capability building. As this paper demonstrates, this can involve both intra- and inter-firm learning and learning between foreign as well as national firms, with important implications for resulting levels of capability building. Secondly, a misleading distinction is implied between technology innovation and diffusion, viewing them as two separate activities and hence overlooking the additional creative engagement, improvement, and diversification of technologies acquired from foreign sources by latecomer firms. Creative learning and innovation efforts often continue during the diffusion process, which involves more than the simple and passive acquisition of imported machinery or product designs, and the assimilation of related operating skills (Bell and Pavitt 1993). In the current paper, for example, firms in Group 1 devoted substantial internal efforts to engage creatively with a technology design originally acquired from a foreign license partner, which contributed significantly to technological capability building. Subsequently, the firms in Group 2 combined internal efforts with imitative learning from their competitors in Group 1 and the import of foreign technology thereby became part of ongoing learning activities in the local economy. This implies a need for further research exploring the additional learning activities associated with technology diffusion and how this relates to technological capability building in cleantech industries and other industrial sectors.

An additional area to which this paper speaks and which warrants further attention is the widespread assumption that lower carbon development trajectories somehow necessitate the rapid introduction of "radical", or "disruptive", new-to-the world types of innovations. Such radical innovations are commonly identified as the main basis of correspondingly radical shifts towards more sustainable economic development. This understanding reduces the importance of incremental innovations which involve longer-term and gradual learning and experimentation efforts. Since such innovations are typically at the lower end of the spectrum of innovative novelty, such as being new-to-the firm or local market, they are often considered less important in the extant innovation literature (Fagerberg, 2005). These types of innovations may, however, be of equal, if not more importance in achieving low carbon development, not least because it is often incremental innovation that characterise the gradual development of technological capabilities in developing country firms (Bell, 2009; Ockwell and Mallett, 2012). In this paper, for example, incremental learning efforts were observed to enable some firms to gradually overcome technical challenges, which resulted in improvements in both performance and technological capabilities. There would therefore be value in additional research that explores in more detail the relationships between longer-term, incremental firm-level learning efforts and the development of relevant capabilities in relation to low carbon technologies at a regional or national scale. Indeed, the issue of scale is one which, to date, is surprisingly absent in existing studies and an area where engagement from the fields of economic and development geography could make important contributions to advancing the theoretical treatment of technology transfer and low carbon development more broadly.

Finally, most research in this field focuses on technology transfer and innovation in the context of potential or existing commercial markets in developing countries. As Sagar (2009) emphasises, there is also a need for research in the context of the development needs of poor people in the absence of commercial markets for relevant technologies or innovation efforts. This might also apply to examples where these market opportunities are nascent but could potentially be harnessed through new approaches to energy service delivery, such as emerging ideas around solar lighting provision via communal charging stations and mobile phone based hire-purchase agreements. This also alludes to a further emerging research area addressing the needs of marginalised groups and the radically different distributional implications of alternative low carbon development pathways (see e.g. Leach et al., 2010).

7. CONCLUSION

This paper's detailed, firm level analysis of the Malaysian biomass power equipment industry illustrates a range of inter-firm differences in the combination of learning mechanisms employed in making technological advances, as well as important differences in the relative levels of resources dedicated to exploiting these learning mechanisms. This suggests some important relationships between patterns and intensities of learning mechanisms and the level of technological capability building achieved by firms. In particular, firms that dedicated significant resources to a combination of learning from foreign partners and planned learning from their own experimentation were observed to have achieved most progress in terms of technological capability building. Nevertheless, important (albeit not as significant) advances in technological capability building were also made by firms who learned from imitating national competitor firms, the latter having learned from interactions with foreign partners. This suggests the role of local knowledge spillovers ought not be underestimated, although, significantly, firms learning from such local spillovers failed to advance beyond extra basic operating technological capabilities, as compared to those firms who proactively pursued learning from foreign partners who advanced to basic innovative levels of technological capabilities. Importantly, however, this paper found cases of firms who had tended to learn by imitating local competitors, but who had failed to take advantage of potential opportunities to learn from commercial interactions with overseas technology partners. This implies that in some cases a lack of technological capability building through learning from foreign partners is due more to a lack of intra-firm strategic decisions to dedicate resources to such learning than a lack of an opportunity to do so. Significant work remains to be done, both in terms of empirical research across different contexts and in terms of theory building, to make sense of these and other relevant insights on the role of learning and technological capability building in the broader context of sustained, low carbon development and technological change.

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